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MICRO-CONTROLLABLE, MULTI-FUNCTIONAL INTERFACE MODULE FOR DIGITAL MP: A WEARABLE COMPUTER SECURITY APPLICATION

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14. ABSTRACT
The objective of this work was the creation of a wearable human-computer interface system. This system is intended to provide the dismounted soldier with a hands-free lightweight display, camera, and audio interface to a wearable computer. The display consists of a miniature flat panel LCD and optical system which magnifies it to create a 16-20 degree-wide image at a comfortable viewing distance. The display is mounted on or in eyeglasses for hands-free operation, and provides clear lines of sight around the display to allow the user to perform his or her duties. The headset also incorporates a high-resolution camera for reconnaissance and capture of images for face recognition. The user can communicate with the computer using either audio, including voice command and control, or with a pointing device for more discrete operation. An industrial design effort was undertaken to ensure the ergonomics of the final headset as well as aesthetic acceptability. Finally, the user interface software running on the wearable computer was optimized for operation in a wearable application.

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PREFACE AND ACKNOWLEDGEMENTS

This is an accounting of work performed for the U.S. Army Research, Development and Engineering Command (RDECOM), Natick Soldier Center, Natick, MA, and the Defense Advanced Research Projects Agency (DARPA), Arlington, VA, during the period October 2002 through March 2004 under Contract Number DAAD16-00-C-9277. The findings and interpretations reported here are the views of the MicroOptical Corporation, Westwood, MA and do not reflect the views of the United States Government and the Department of Defense (DOD).

The objective of the work was the creation of a wearable human-computer interface system. The system is intended to provide the dismounted soldier with a hands-free, lightweight display, camera and audio interface to a wearable computer.

The Project Team is grateful to E. C. Urban, formerly Program Manager, Electronic Technology Office (ETO), DARPA and for H. Girolamo, RDECOM Soldier Technology Transition Office, for their interest in and steadfast support of this work. MicroOptical wishes to thank the following individuals for their contributions to this effort and related programs:

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- Billy Higeons, U.S. Army Military Police School, Fort Polk, LA, who as a retired Military Police Officer provided user in the loop guidance and facilitated the total effort with the MP School.

MICRO-CONTROLLABLE, MULTI-FUNCTIONAL INTERFACE MODULE FOR DIGITAL MP: A WEARABLE COMPUTER SECURITY APPLICATION

SUMMARY

The objective of this work was the creation of a wearable human-computer interface system. This system is intended to provide the dismounted soldier with a hands-free, light weight, display, camera, and audio interface to a wearable computer. The display consists of a miniature flat panel LCD and optical system which magnifies it to create a 16-20° wide image at a comfortable viewing distance. The display is mounted on or in eyeglasses for hands-free operation, and provides clear lines of sight around the display to allow the user to perform his duties. The headset also incorporates a high resolution camera for reconnaissance and capture of images for face recognition. The user can communicate with the computer using either audio, including voice command and control, or with a pointing device for more discrete operation. An industrial design effort was undertaken to ensure the ergonomics of the final headset as well as aesthetic acceptability. Finally, the user interface software running on the wearable computer was optimized for operation in a wearable application.

1 INTRODUCTION

The objective of this work was the creation of a wearable human-computer interface system. This system is intended to provide the dismounted soldier with a hands-free, light weight, display, camera, and audio interface to a wearable computer. In this section we review the contract objectives and outcome. Details are provided in the sections to follow.

This work is part of a joint effort between The MicroOptical Corporation, ViA, Inc., the U.S. Army Soldier Systems Center, and the Military Police School at Ft. Polk, LA. MicroOptical's tasks involved the development of the head-mounted interface system. ViA was responsible for the wearable computer. The Soldier Systems Center provided human factors analysis and overall project integration. The Military Police School provided user analysis and field trials. This report covers only the development of the eyeglass interface system, which is termed the micro-controllable multi-functional interface module (MMIM). The entire system including computer, peripherals, and MMIM has been termed the "Digital MP."

A large number of subcontractors participated in the creation of the MMIM system. The subcontractors included: Optikos and MSOD for optical design; Stratos Product Development Group for industrial design; Aox Inc. for IEEE 1394 circuit development, MicroDisplay Corporation for the liquid crystal display; Trisen Systems, Inc. for videometric head tracking; and Randolph Engineering for eyeglass frame development. In the final system revision, Visionics (now Identix, Inc.) was subcontracted to revise the face recognition portion of the software to include automatic image capture and face recognition capability. MicroOptical's effort was managed by Mark Spitzer and Paul Zavracky. Contributors at MicroOptical included Robert McClelland, Paul Aquilino, Noa Rensing, Mark Olson, and John Crawford.

1.1 PROJECT OBJECTIVE

The purpose of the MicroOptical work is development and demonstration of an eyeglass-based MMIM interface system which would provide an interface for all of the functions of the Digital MP system. These functions include:

1. Face recognition – in which the head-mounted camera is aimed at an unknown person, the person's face is photographed and compared to a database, and information returned from the database is shown on the head-mounted display.

2. Route Recon – in which the head-mounted camera is used to photograph and store the images of objects during route reconnaissance.

3. Peer-to-peer conferencing – in which members of a team share audio and video.

4. Voice command – in which spoken commands are used to control the computer operation.

5. Head-tracking – for future applications involving augmented reality.

6. Legacy compatibility – in which the system shows images from FBCB2 sources.

These functional requirements placed hardware requirements on all of the subsystems. Specifications for each subsystem are discussed in Section 1.2.

The first objective of the program was to develop the technology that would make such a system possible. The second project objective was to integrate the technologies and demonstrate a working system. The final objective was to deliver working systems to the Soldier Center for testing at Ft. Polk. All objectives were obtained.

1.2 MMIM SYSTEM REQUIREMENTS

The above system functions required the development of specifications for the subsystems of the MMIM system. Table 1 summarizes the initial specifications for the display system. The camera system is specified in Table 2. Audio is specified in Table 3.

Table 1. Display Specifications

Resolution	640x480 pixels or greater, 60 Hz refresh
Color depth	18 bit color
Cable length	4 ft from viewer to belt worn controls
Field of view	20° Horizontal, 15° Diagonal
Focus range	2 m

Table 2. Camera Specifications

Sensor	640x480 pixels, 1/3" active area color CMOS sensor
Frame rate (min)	15 fps @ 640x480, 30 fps @ 320x240
Cable length	4 ft from eyeglasses to control box
Field of view	Approximately 20° Horizontal
Distortion	<2%
Focus	Adjustable, 2ft to infinity

Table 3. Audio

Microphone	Noise canceling, flat frequency response to 5 KHz
Digitization	11 KHz
Speaker	Monophonic

1.3 RESULTS

Figure 1 shows a photograph of the completed MMIM system. Systems meeting the above specifications were delivered for testing at Ft. Polk, and the result is summarized in Section 7 of this report. Based on the responses to the field testing, the hardware and software were revised as described in Section 8.

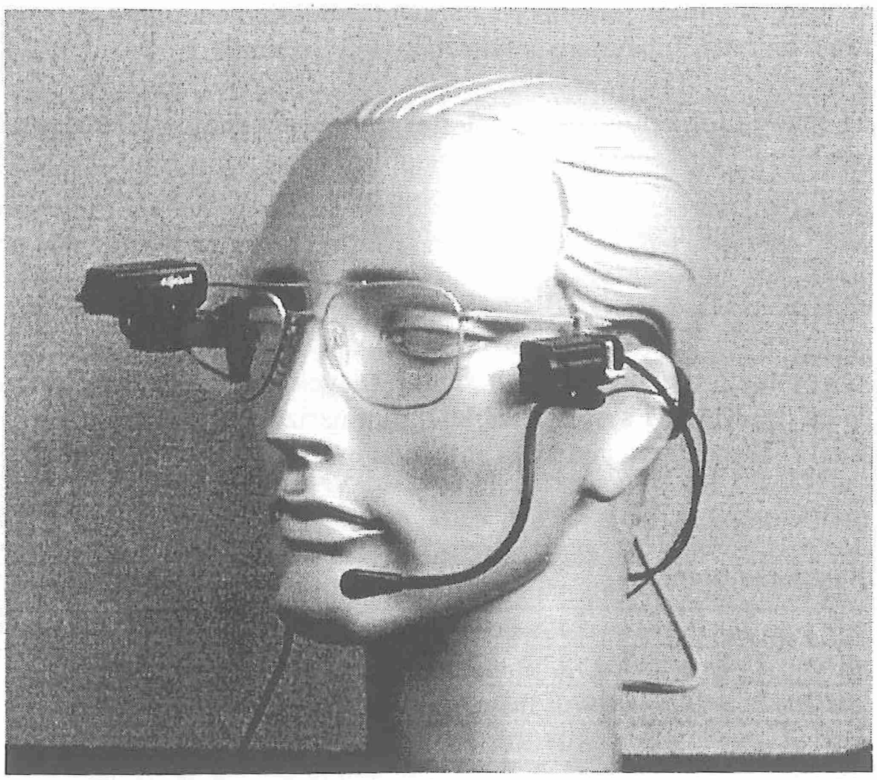


Figure 1. Completed MMIM System with SVGA display

2 SVGA Display Subsystem

The display subsystem comprises two main parts. The first is the active matrix liquid crystal display (AMLCD), and the second is the optical system for illuminating and viewing the display.

2.1 AMLCD Development

The MMIM system requires a small liquid crystal display capable of integration in eyewear. To this end, Microdisplay Corporation began the layout of a new reflective AMLCD. Although the original system specification called for VGA (640x480) resolution, Microdisplay Corporation offered to build an SVGA (800x600) display for the project. The pixel pitch was approximately 10 μm, and thus the viewable area of the display was 8 mm by 6 mm.

Color was obtained by using the time sequential color frame method. Thus, to obtain a frame rate of 60 Hz, the display was run at a frame rate of 180 Hz which was sub-divided into red, green and blue frames. The use of this technique required a frame buffer. Integration of a frame buffer within the display was not feasible; therefore, complete integration using a red/green/blue (RGB) signal as input was not possible. However, cable was developed that enabled the display to be connected conveniently to drive circuitry mounted off the head.

Fig. 2 illustrates the front and back view of the display. The AMLCD is mounted to a flex-PC board which terminates in a connector matching the cable.

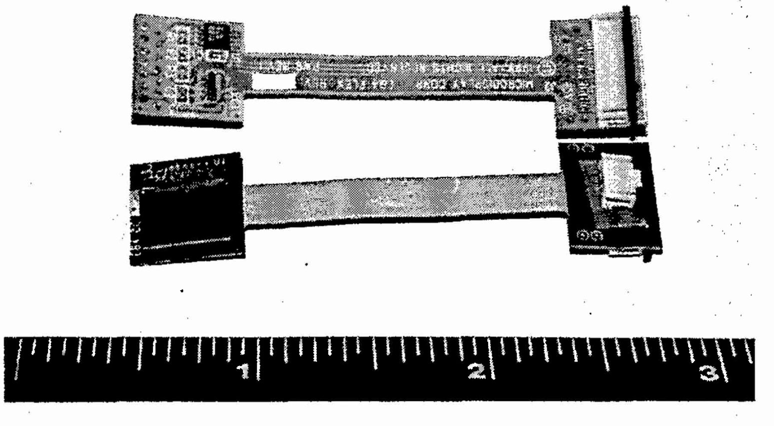


Figure 2. Photograph of the Front and Back of the AMLCD Developed in this Work.

Experimental drive electronics for the display were provided by Microdisplay. Fig. 2 illustrates one of the sets of electronics. The input to the circuit was conventional analog

RGB. Thus it was necessary to develop additional drive electronics for IEEE 1394 input. Initial units were delivered to the Army for evaluation using this type of electronic drive circuitry.

Figure 3 shows an electronics package created by MicroOptical using the Microdisplay drive board, and a USB camera drive board. This allowed connection to the ViA computer by conventional techniques. Later units demonstrated IEEE 1394 drives; however, we found that the Microsoft Windows 2000 operating system is not fully compatible with an IEEE 1394 display drive. While a Firewire display is supported by the operating system, it cannot use it as a primary display. Thus the development of the IEEE 1394 systems and the required ASIC was not fully implemented.

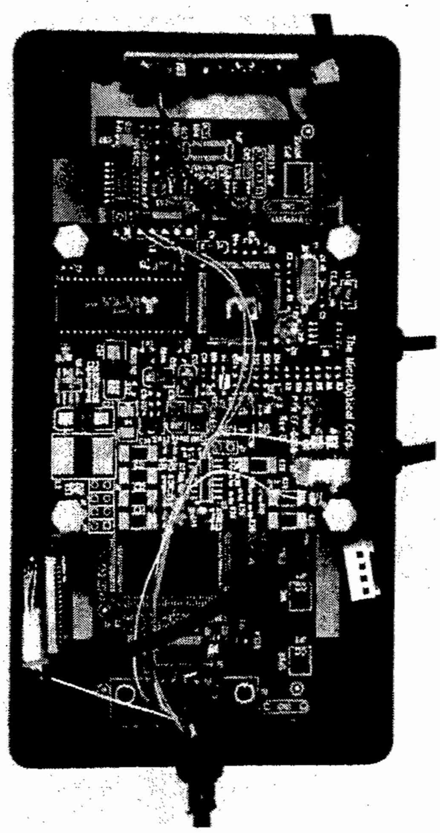


Figure 3. Photograph of Drive Electronics for Initial Display and Camera.

2.2 Optical System

The optical system comprises and illuminator and a magnifier.

2.2.1 Illuminator

The AMLCD fabricated by Microdisplay requires a front illumination system. The illumination system provides collimated polarized light to the display, and analyzes the reflected light in a second polarizer.

A number of approaches to analyzing the polarized light from the reflected display are possible, including the use of film polarizers made by Polaroid (now a division of 3M). The optical design also included high quality thin film polarizing beam splitter coatings designed specifically for our requirements and that were deposited on glass prisms. This provided us with the highest quality image; however, the weight of the system was increased by the use of solid glass cubes.

2.2.2 Integrated Magnifier

Two types of magnifying optical systems were constructed in this program. The first was an integrated eyeglass lens which used a polarizing cube illuminator as described above and a polarizing eyepiece to allow the user to see through the eyepiece when the display is not in use. This eyepiece is shown in Fig. 4. Note that the illuminator is external to the eyeglass lens. This allows the introduction of a field lens to improve the image.

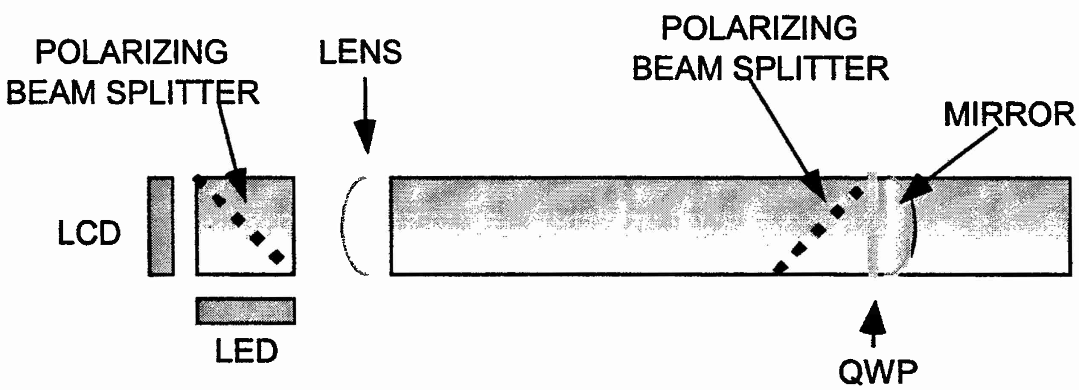


Figure 4. Integrated Magnifying "See-through" Eyepiece.

Eyewear Display were formed using the lens shown in Fig. 4. Note that this is a see-through eyepiece design. The reason see-through is preferred in an integrated optical approach is that the user cannot move the optics out of the way when using the eyewear with the display turned off. If this were not a see-through system, the user must remove the eyewear to remove the dark spot in his vision. Thus see-through optics allow multiple uses of the eyewear, including augmented reality systems in which information is overlayed through the see-through eyepiece. Fig. 5 shows a photograph of the eyewear. The industrial design that went into the creation of the eyewear in Fig. 5 will be discussed in Section 5.

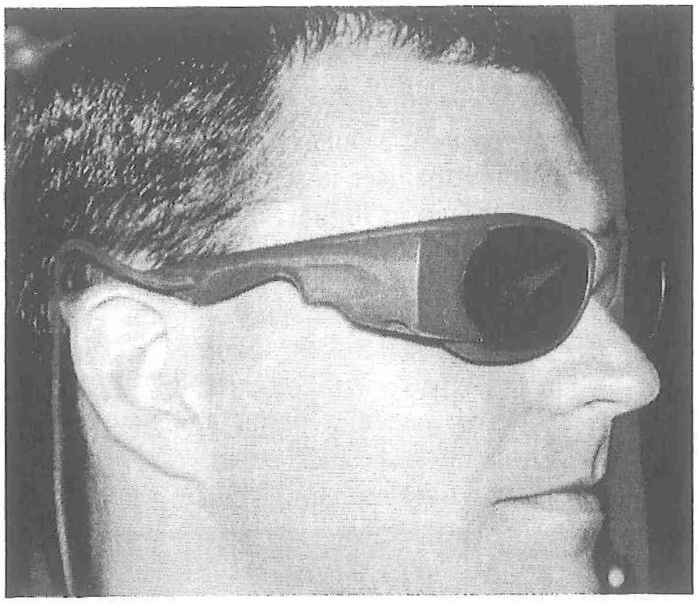


Figure 5. Photograph of Integrated Eyewear With Reflective SVGA Display. The Horizontal FOV is 16°.

2.2.3 Clip-on Magnifier

The clip-on version of this system is illustrated in Fig. 6. These optics are not see through, owing to the location of the mirror. This design was chosen because the user can move the clip-on out of his field of view when it is not in use[1]. The use of occluding optics of this type provides higher contrast in high brightness ambient light environment. Fig. 7 shows a photograph of the final display system, built in a clip-on form

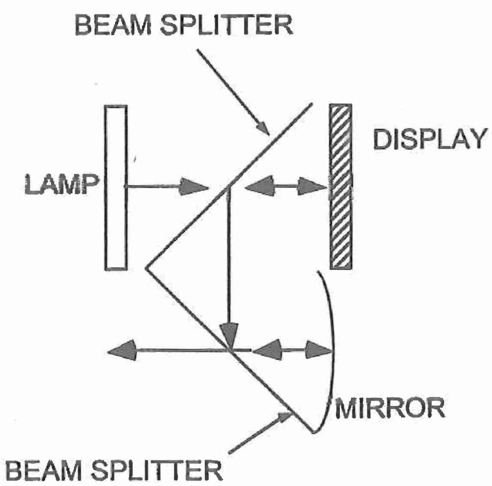


Figure 6. Clip-on Magnifier and Illuminator System.

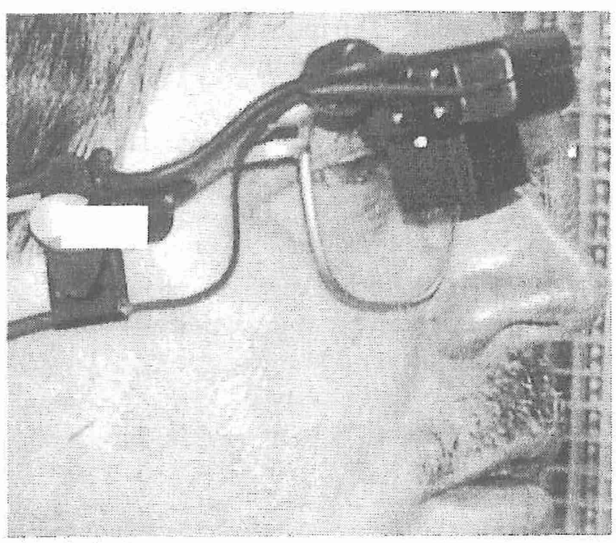


Figure 7. Photograph of the SVGA Clip-on Display.

3 Camera Subsystem

The camera subsystem comprises three main parts: (1) the lens, (2) the CMOS imager integrated circuit, and (3) the interface electronics. The design of the lens is related highly to the specifications of the CMOS chip, owing to exposure requirements, head motion, and other factors.

3.1 Lens Design

The lens design was carried out by Optikos. The initial assumptions were the following:

(1) VGA (640x480) Image Sensor
(2) 9.0 μm Square Pixel
(3) 7.2 mm Sensor Diagonal
(4) 30 pixels Between Eyes for Face Recognition

The lens design task comprised a determination of the exposure, aperture, resolution and head motion requirements for the camera. The criteria imposed on the design was to provide the smallest possible system consistent with indoor light levels, head motion characteristic of a person holding the head reasonably still (<1 °/s rotation) , and which provided a 640x480 image with pixel blur of 1 pixel.

Initial work examined the depth of focus that could be provided for different aperture stops. In each zone, once the focus is set, the image is in focus for all positions within the zone. An optical system with a single zone would not need any focus adjustment; however, a camera with such a high depth of focus requires an unacceptably small aperture, owing to the sensitivity range of current CMOS sensors.

The initial lens design was studied for two apertures yielding f/3 and f/7 systems and the resulting focus zones are as follows:

(1) f/3: 5.8 ft to 8.8 ft, 9 ft to 17.5 ft, and 17.5 ft to infinity
(2) f/7: 3.75 ft to 7.5 ft, and 7.5 ft to infinity

Thus with the smaller aperture, the camera had two simple focus zones in which VGA resolution was obtainable for the entire zone. Owing to the depth of field and field of view (20° horizontal), the lens design effort showed that a person would have to be within 12.9 ft to have 30 pixels between the eyes and thus to be recognized by face recognition software.

Exposure calculations were carried out. For a sensor integration of 33 ms, at f/3 the systems requires 33.4 foot candles, and for f/7 the system requires 18.4 foot candles.

Blur calculations were carried out to determine the effect of head rotation to the left or right. The horizontal field of view of 20° translates to and angle of 0.03 degrees per column. Therefore there will be pixel blur of one pixel if the head moves at a rate of greater than 1 °/s.

3.2 CMOS Sensor Selection

The selection of a CMOS sensor was based on a requirement for VGA resolution and exposure times that would permit a degree of head motion in daylight situations. A CMOS sensor was selected over a CCD sensor owing to the desire to reduce the power consumption to the lowest levels possible, and to the belief that eventually CMOS devices would outperform CCD sensors, ultimately at lower prices. We examined two principal manufacturers: Hewlett-Packard and Hyundai.

A preliminary data sheet for the Hyundai CMOS imager was obtained and compared with five other similar devices, including HP CMOS sensors. The Hyundai imager which was recommended by Aox was determined to be the best fit to our requirements. The Hyundai device has a built-in eight bit analog to digital converter.

To assess the performance of the Hyundai sensor in a face recognition application, we have made a calculation of the resolution for a system with an 18 degree field of view (FOV). Table 4 shows the performance of the 640x480 camera sensor in such a system. It can be seen that at 5 feet the target width captured by the camera is 1.56 feet. An object in this focal plane at 5 feet is resolved by 34 lines per inch. A key factor in the performance of a face recognition system is the number of lines between the eyes. If we assume that the typical interpupillary distance is 65 mm, we find that at five feet, the system provides 87 lines which corresponds to a measurement of IPD of better than 1 mm. We believe that even at 10 ft the system should have adequate resolution for face recognition.

Table 4. Hyundai Device With 18 Degree FOV Optics

Target Distance (feet)	Target Size (feet)	Vertical Lines Per Inch	Vertical Lines per 65 mm
3	0.94	57	145
5	1.56	34	87
10	3.13	17	44
15	4.69	11	29
25	7.82	7	17

Note: Horizontal resolution is 640 lines.

The heart of the camera system is a CMOS sensor capable of VGA resolution. The sensor is shown in its package and mounted to a circuit board in Fig. 3. Also shown in the figure are the optics, which have a focal length of 17 mm and f/3.5. The camera optics were designed for face recognition by Optikos, and through considerations related to this recognition, we determined that the field of view should be 19° horizontal by 14.5° vertical. Distortion is less than 2%. The camera has a focus range of 2 ft to infinity, and is provisioned for servo focusing. The weight of the camera is 37 grams.

3.3 Interface Electronics

Development of interface electronics comprised two parts: (1) initial development of USB drive electronics, and final development of IEEE 1394 drive electronics.

The USB drive electronics uses an integrated circuit developed by Aox. This IC was used in a board designed by MicroOptical and shown in Fig. 8. This interface was used in the development and testing of the camera.

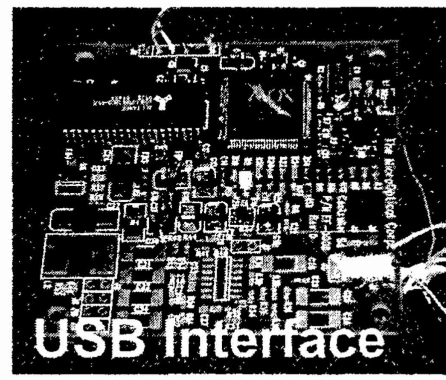


Figure 8. USB Interface Electronics Using an Aox Integrated Circuit.

3.4 Camera Subsystem Initial Design

Fig. 9 shows a solid model illustration of the mechanical design of the camera. Note that a prism is used to turn the image from the lens barrel into the CMOS sensor. A picture of the packaged CMOS sensor is shown in Fig. 10. The use of a turning prism mounted on top of the CMOS sensor allows the camera to be made more compact, and also allows a reduction in the back focal length of the camera lens system.

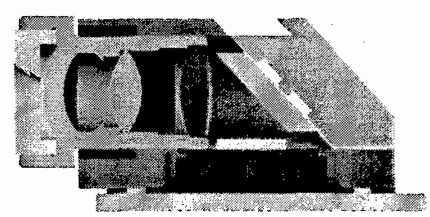


Figure 9. Solid Model of the Initial Camera Design.

The lens is fitted with a removable aperture so that the camera could be tested with two f-stops. Consistent with the design described above, the high number of surfaces in the camera lens creates an undistorted image capable of VGA resolution and very well suited for face recognition. A photograph if the initial camera design is shown in Fig. 11.

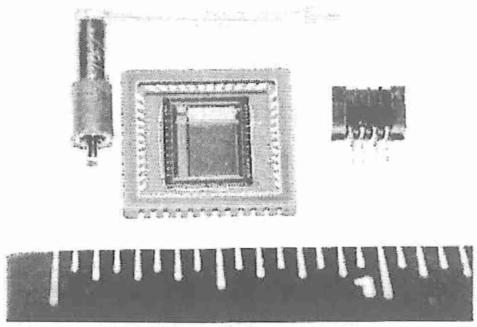


Figure 10. CMOS Sensor, Focus Servo and Servo Drive Circuit.

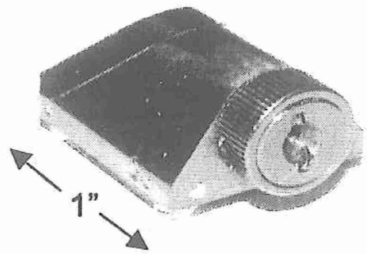


Figure 11. Photograph of Camera Made in Accordance with the Initial Camera Design.

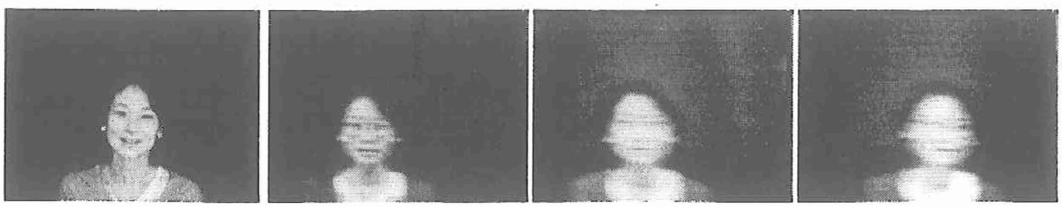
3.5 Camera Testing

The camera was tested using the USB interface with Face-It™ software to determine how well it performed in a face recognition task. Figure 12 shows the results of testing at three distances from the camera. The software is able to recognize the subject at 5 and 10 feet.

Five Feet	Ten Feet	Fifteen Feet
40 PBE	21 PBE	14 PBE
Score 8.4	Score 8.3	Not matched

Figure 12 . Outdoor Testing of Camera Using Face Recognition Software (in shade, f/7, using the center 320x240 area).

The camera was mounted on a rotation platform to simulate head motion. Figure 13 shows the results of testing the camera in this way. Note that for rotation rates above 5 degrees per second, the camera was not able to capture a reliable image. This shows the need for good lighting in face recognition applications. Such lighting reduces the exposure time for the camera sensor and reduces blur.



Still	**5°/s**	**7°/s**	**8°/s**
Score 9.3	**Score 8.0**	**Score 7.3**	**Score 6.7**

Figure. 13 . Camera Testing on Rotation Platform.

3.6 Camera Subsystem Final Design

After gathering some experience in using the camera, it was decided that the performance of the f/# 7 system was preferable in most situations, due to its greater depth of focus. While the faster lens offers somewhat better low light performance, the sensitivity of the sensor is such that in most situations the f/#7 performance was sufficient. By eliminating the f/# 3 option and redesigning for a smaller lens diameter we both reduced the physical size of the camera and simplified its operation. At ray trace of the final design is shown in Fig. 14 . Note that the use of a solid prism allows a shortening of the physical path length as compared to the focal length. The transfer function for this optical system is shown in Fig. 15. Fig. 16 shows the measurement results of the modulation transfer function.

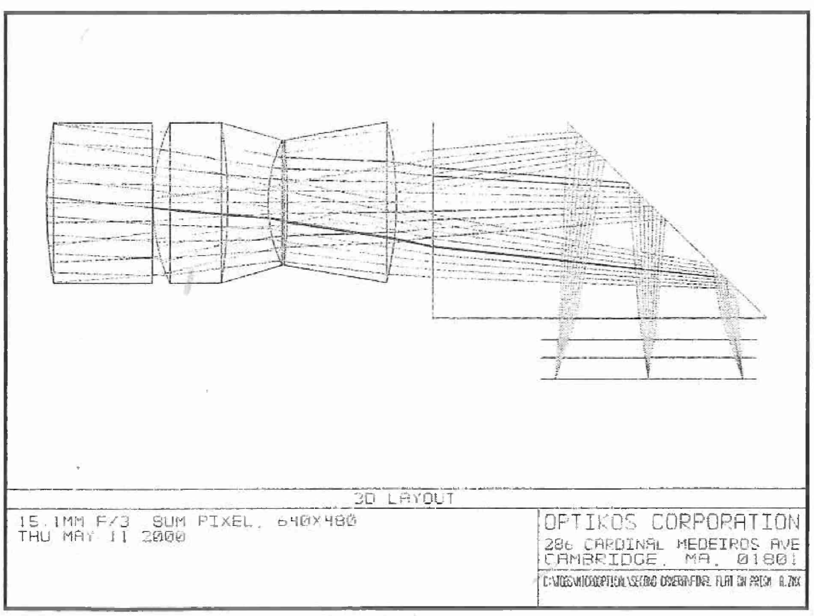


Figure 14. Ray Trace of the Camera Lens Optics.

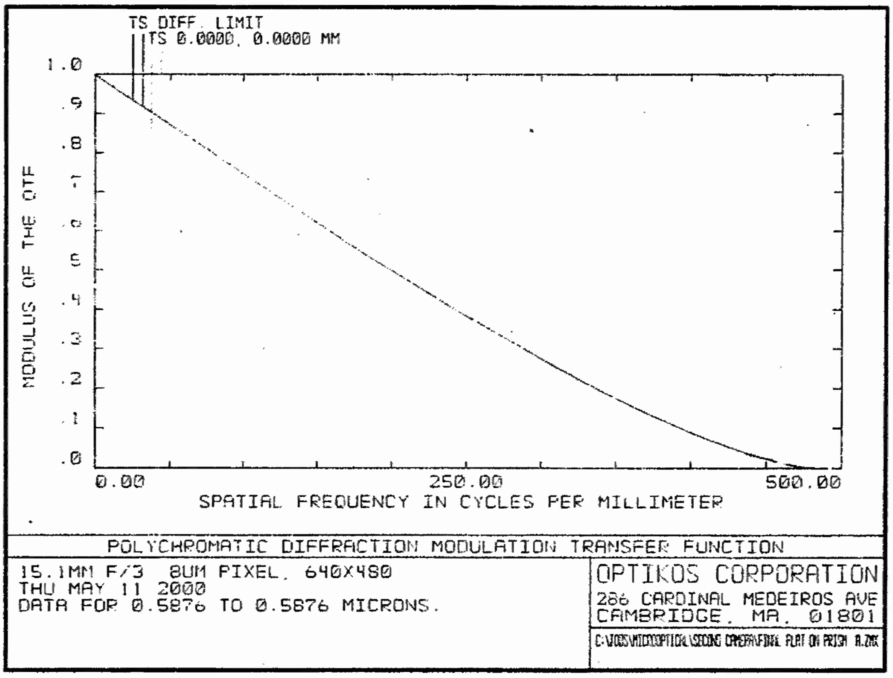


Figure 15. Transfer Function for the Final Camera Lens Design.

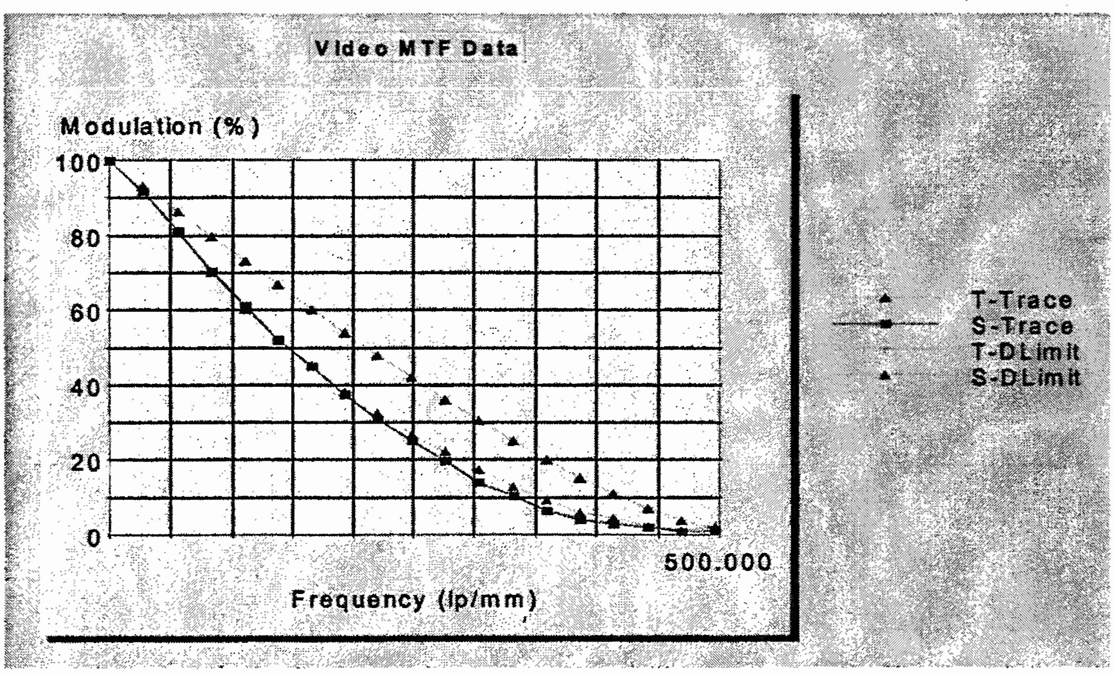


Figure 16. Actual MTF Measurement for the Final Camera Lens Design.

A model of the camera lens design is shown in Figure 17, and Figure 18 shows the lens system mounted on the sensor. It can be seen that the camera, sensor and focus servo are mounted on a printed circuit board which houses the servo controls and cable terminations. The model may be compared to photographs of the actual finished camera (without housing) in Figure 19. It can be seen from the photograph that the size of the system is dictated by the package that houses the CMOS sensor. If this package could be reduced, the overall size of the camera could be reduced.

The final optical system has been designed to accommodate camera pixels with an 8 μm pitch. The field of view is 20° by 15°. The focal length of the lens system is 15.1 mm. A comparison of the initial and final designs is shown in Fig. 20.

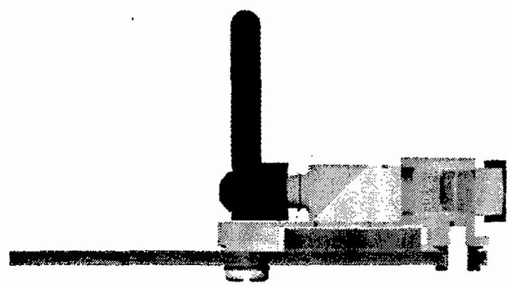


Figure 17. Lens Barrel Mechanical Design.

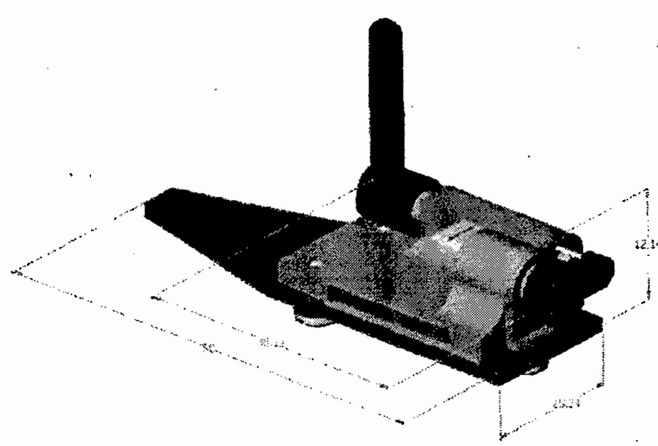


Figure 18. Solid Model of the Final Camera Design. Dimensions are in mm.

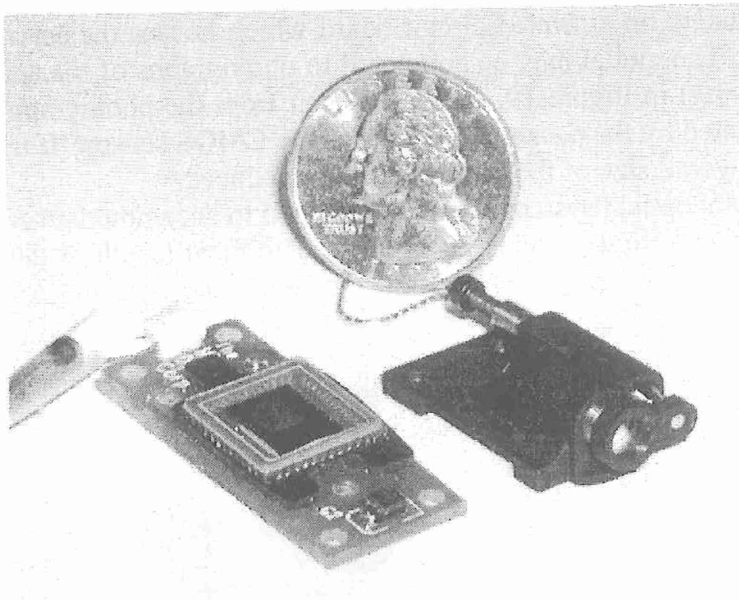


Figure 19. Photograph of the Camera Sensor and Printed Circuit Board (left), and Lens System and Servo (right).

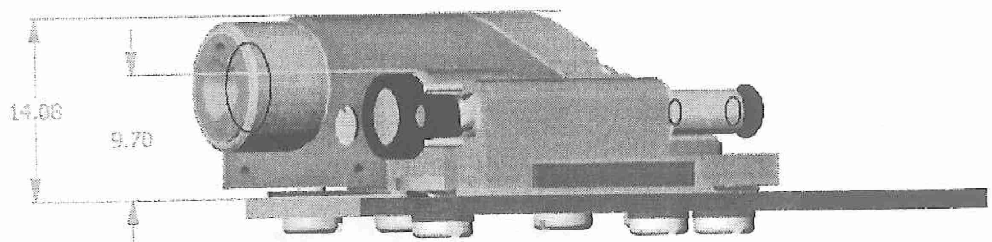


Figure 20. Comparison of Initial and Final Camera Design.

4 Audio Subsystem

The audio subsystem comprised the microphone and speaker. A number of alternatives were investigated and will be reviewed in the sections to follow.

4.1 Microphones

Three types of microphones were evaluated for this program. The first comprised a bone conductivity microphone which could be mounted in the ear as part of an earpiece, or against the head. The second comprised a noise-canceling microphone of the type typically used for voice recognition. Since the digital MP system was to use voice recognition, the selection of the microphone was of critical importance. (The use of a bone microphone would only be acceptable if it provided good performance in a voice recognition task.) The third microphone comprised a hearing aid transducer mounted in an eyeglass temple.

Evaluation of microphones was carried out using the Microsoft Windows98™ Sound Recorder, Dragon Systems Naturally Speaking™ and Conversa Web™. Tests were made in a quiet lab and with and without a calibrated noise source. A microphone test protocol was created which comprised dictation of a fixed set of words and phrases, and a score was generated corresponding to the number of correct times the system recognized the spoken words. The tests protocol utilized 86 html link words and an acoustic environment consisting of speech shaped background noise at several calibrated levels, which is a standard methodology for testing hearing aids and similar audio devices.

The devices tested comprised (1) an MMIM directional microphone made by MicroOptical and integrated in an eyeglass temple, (2) a noise-canceling microphone on boom (the VXI Parrot), a bone conduction microphone (the Temco Voiceducer). Microphone arrays which would seem to be promising were not tested owing to a requirement for a large amount of digital signal processing.

The data from background noise tests are shown in Fig. 21. It can be seen that the MMIM and VXI microphones have the best recognition accuracy. However, as the noise level is raised, the noise-canceling boom microphone yields the best performance. Bone conductivity microphones show immunity to noise, but poor recognition accuracy owing to the absence of adequate frequency response above 1100 Hz (see Fig. 22). While they are promising for future development, their use would require the creation of specialized speech recognition acoustic models, which is beyond the scope of this project. For this reason, work with bone conductivity microphones was discontinued.

After we determined that the noise-canceling boom microphone was the best choice, a number of noise canceling boom microphones were evaluated. Best results were obtained with a Gentex microphone, which was used in the final MMIM system. Fig. 23 shows a photograph of the microphone.

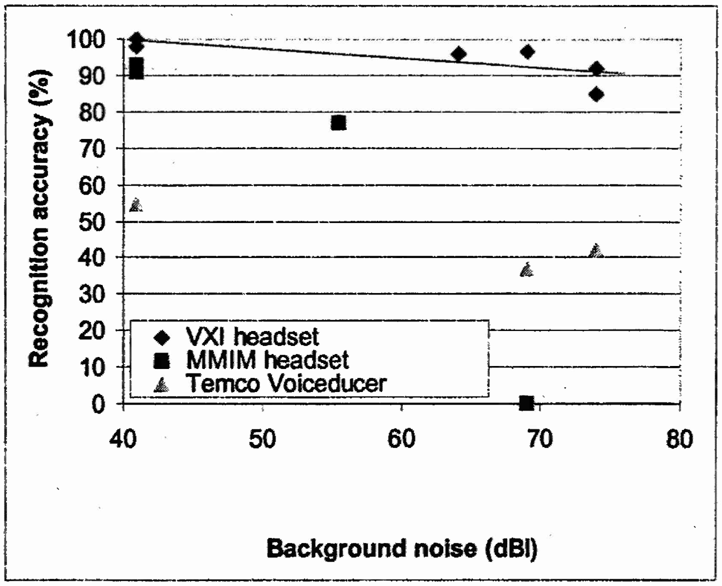


Figure 21. Background Noise Tests.

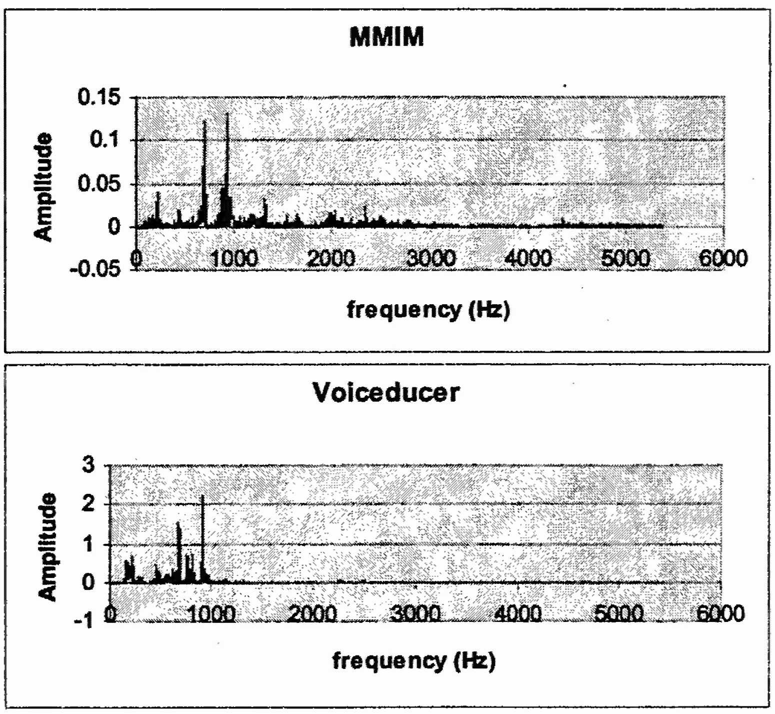


Figure 22. Comparison of Voiceducer and MMIM Microphone Frequency Response.

Figure 23. Gentex Noise Canceling Microphone Used in the Final System.

4.2 Ear Phones

A number of ear phone speaker devices were considered. The most promising comprised devices comprised (1) a transducer and pipe that can be placed near the ear, so that hearing is unobstructed, or (2) a transducer placed in an ear plug so that very high noise levels are attenuated. Either approach was found to be satisfactory and easy to implement. Sound levels from available transducers were high enough to operate in 80 dB noise environments. Fig. 24 shows a photograph of the transducers used in final deliveries. The speaker volume required for audible signals above that noise level would pose a risk to the user's hearing, and we therefore recommend hearing protectors around the speaker for environments with ambient noise levels of 85dB and above[2].

Figure 24. Packaged Transducers Used in Final Deliveries.

4.3 Bluetooth Audio

Bluetooth audio headsets are generally available for use with cellular phones and for other communication applications. At least one manufacturer (Belkin) of Bluetooth adapters for laptops also provides software drivers that enable the headset to be used for voice command and control as well as dictations. While this combination is not recommended by any of the speech recognition software manufacturers, in our tests the combination of a Plantronics headset and the Belkin Bluetooth adapter gave recognition rates comparable to the Gentex microphone.

5 Industrial Design

The industrial effort was undertaken in close collaboration with the mechanical and optical design process. First, functional prototypes were fabricated to test the concept and determine the necessary size and geometry. These were mounted on a sturdy adjustable eyeglass frame developed by Randolph Engineering Corporation to allow the evaluation of the concept by users with different interpupillary distances. The functional prototype is shown in Figure 25.

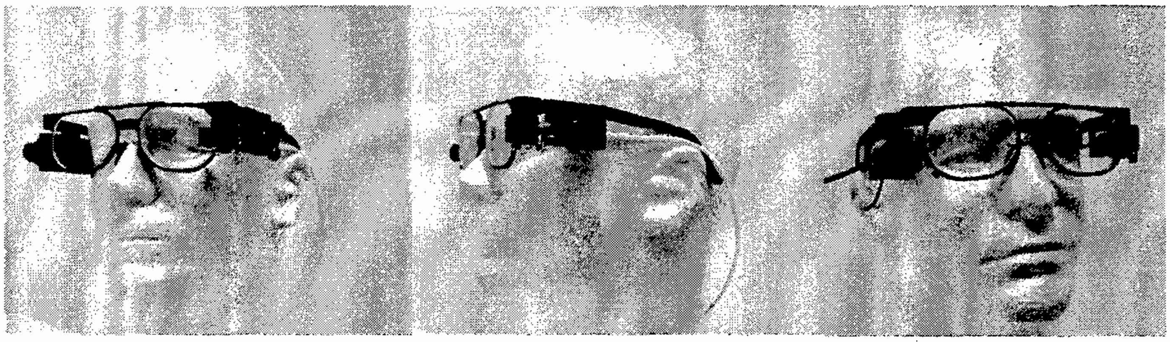


Figure 25. Working Prototypes of Camera and Displays on an Adjustable IPD Frame.

We believe the user acceptance is strongly dependent on both the comfort and appearance of the device. We envision deployment primarily in military or industrial settings that require rugged design and may also necessitate eye protection, so the industrial design approach started with an exploration of safety glasses. These designs provide a rugged, sturdy platform for mounting the optical components, and are designed to be comfortably worn for extended periods of time. The look of the eyewear is also appropriate to the settings, as shown in Figure 26.

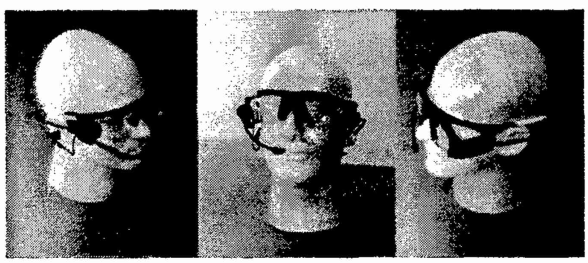


Figure 26. Headset Concepts Based on Safety Glasses.

The next step in the design considered a more integrated approach, in which the components are fully enclosed by the frame, as shown in Figure 27. Note that the glasses retain the padded nosepad and wide frame of the safety glasses. This is aimed at maximizing user comfort and field of view. This design approach would furthermore allow the user to wear corrective glasses under the MMIM headset.

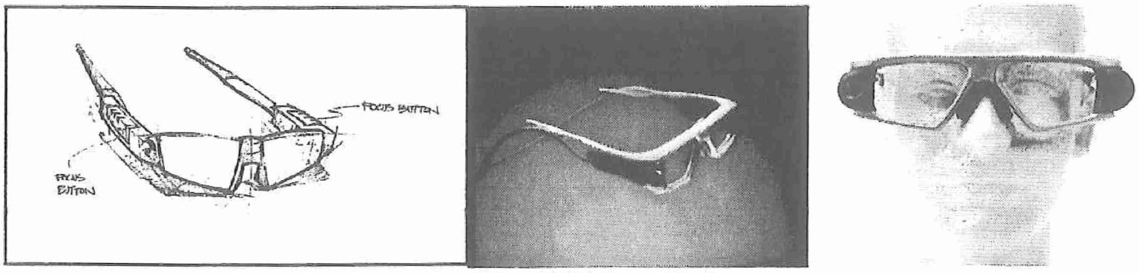


Figure 27. Integrated Glasses Concept Based on Safety Glasses.

An alternative approach to integration is to fabricate a smaller, more compact design. This offers a more discrete and pleasing appearance for non-industrial settings. In this approach, any prescription correction would be incorporated into the electronic headset. Prototypes of the glasses were fabricated by Stratos and tested by Stratos and MicroOptical employees to evaluate fit and functionality, as shown in Figure 28.

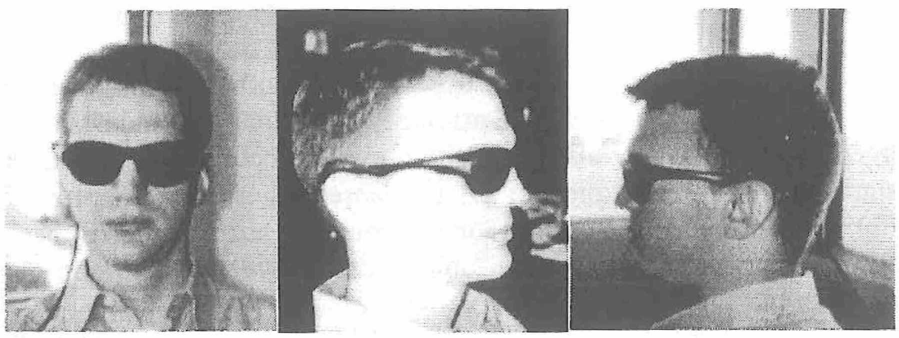


Figure 28. Compact Integrated Glasses Concept.

A more detailed view of two clip-on concepts integrated into safety glasses is shown in Figures 29 and 30. For optical systems integrated into the eyeglass lens, a more compact format close to the head was preferred. The design was refined several times as shown in Figure 31. Finally, more futuristic designs were considered and modeled, as shown in Figure 32. These are not necessarily practical with existing technology, but demonstrate the future potential of the integrated eyeglass approach.

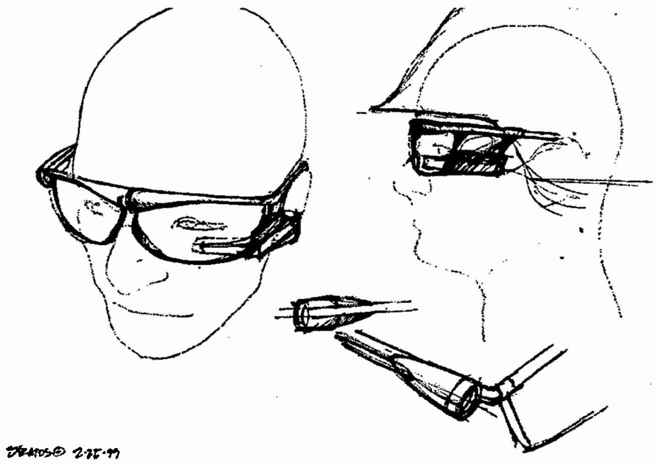


Figure 29. Clip-on Integrated Inside Safety Glasses.

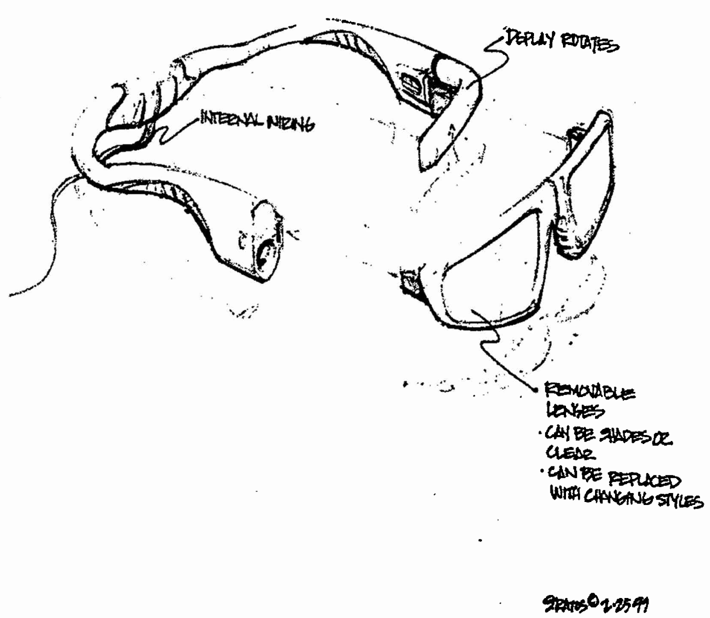


Figure 30. Clip-on Inside Safety Glasses. Hand-written Call-Outs Read (Clockwise from Upper Left) 'Internal Wiring', 'Display Rotates', and 'Removable Lenses -Can be Shades or Clear -Can be Replaced with Changing Styles'.

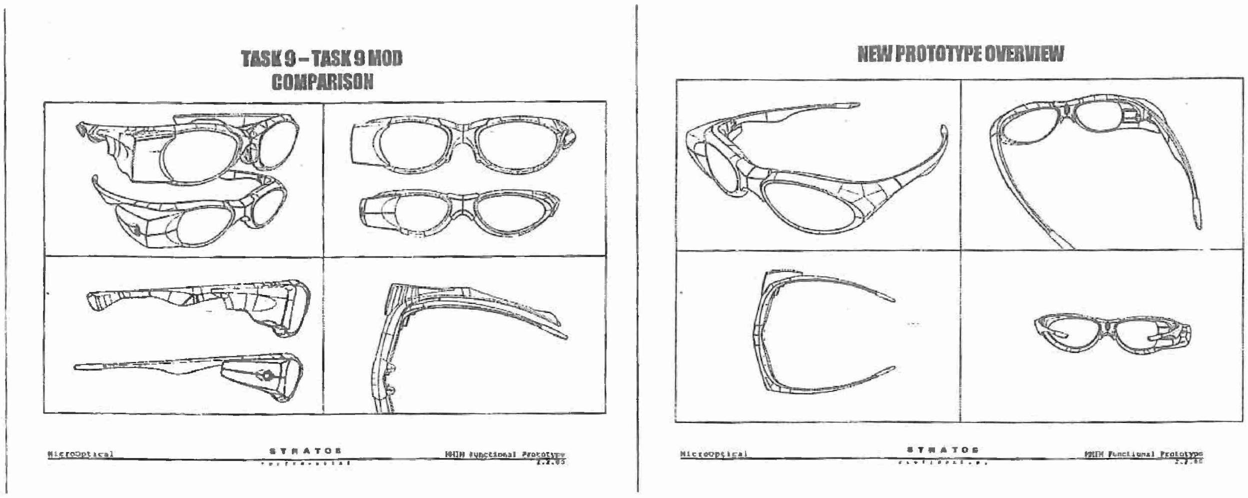


Figure 31. Evolution of Compact Integrated Eyeglass Approach.

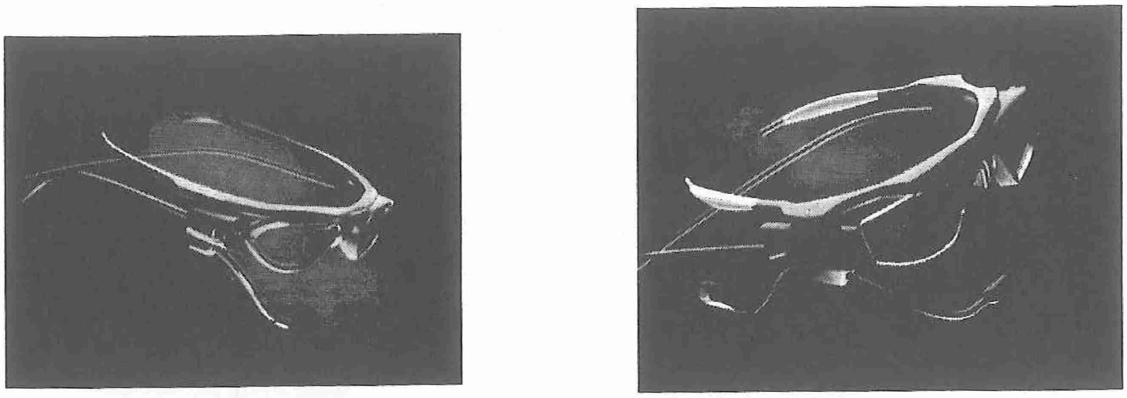


Figure 32. Futuristic Concept Models for Integrated Headsets Based on Safety Glasses.

6 FIELD TESTING

Through a large amount of testing by the Military Police, MicroOptical accumulated a large body of information on user preferences and ergonomics that allowed the development of a system that is easy to use, is compatible with legacy systems (software and hardware), and that is comfortable to wear. This section will review some of the operational tests of the system, evaluation trials and user testing of the system at Ft. Polk, LA from 30 October to 3 November 2000. The objective of the trials at Ft. Polk was to identify critical features of the system that require improvements for application to MP missions and tasks. These trials allowed MicroOptical to evaluate the results of the design efforts.

The system evaluation was focused on all hardware components as well as the computer and the software that supported its operation. Each portion of the system was evaluated for ease of operation, speed and reliability. Fig. 33 shows a photograph of the MPs using the Digital MP system. Evaluation and analysis of the user tests was conducted by James Samson, Senior Human Factors Specialist at the Natick Soldier Center, in Natick MA.[3]

Figure 33. MPs at Ft. Polk Using the Digital MP System.

6.1 VISUAL DISPLAY & EYEWEAR

The MMIM system was evaluated for feel and comfort, appearance/obstruction and clarity/resolution of the visual display. The SVGA display previous described and shown in Fig. 1 was used in the evaluations. The clip-on SVGA monitor has see-around display optics, articulating mounting arm, plano (non prescription) eyeglasses, and is attached electrically to the computer mounted in the user's load bearing vest using a light weight cable of approximately 125 cm in length. A clip-on display was selected to enable the users to make adjustments to the display position (Fig. 34). There was also no need for prescription lenses because the evaluators could mount the display on their own glasses, if required. None of the evaluators had worked with a head-mounted interface prior to this experiment.

Figure 34. MMIM SVGA Eyewear in Use by MPs.

Based on the feedback of the users, the visual display and eyewear were found to be very useful and easy to use. Clarity and resolution were acceptable, especially indoors. Outdoors, some binocular rivalry was observed in bright light, and users found it necessary to block light to their other eye. This problem can be solved by using sunglasses or by modifications to the eyewear itself.

Regarding comfort, one of the principal issues involved the stabilization and weight of the display. Stabilization was obtained by using a fabric-based elastic retaining strap behind the head. This strap was effective in holding the eyewear system in place, but it caused the nose pieces to press against the nose and resulted in discomfort. It is believed that an integrated glasses-based system[4] would eliminate this discomfort because the weight of the integrated system has the potential to be lower and more balanced.

The appearance/obstruction of the display and eyewear was such that there was some obstruction to the user's vision. This obstruction resulted from the optical housing for the

SVGA display. Had another display been used, such as the VGA clip-on display (640x 480), this would not have been an issue. Also, the use of the integrated eyeglass display rather that the high resolution clip-on would have eliminated the occlusion of the user's vision. Some users suggested that the clip-on display be mounted on a helmet. According to Mr. Sampson, "What complicates the evaluation of a head-mounted display for a user is the type of mounting. It is hard to separate the likes and dislikes of the display itself from the mounting of the display." An experiment using the embedded eyeglass display would be of benefit.

6.2 HEAD-MOUNTED CAMERA

The head-mounted camera was found to be very useful. It was found to be easy to align to the user's view. The head-mounted camera hardware was also found to be reliable. Regarding function and utility the users all agreed that a camera is very useful for face recognition and for capturing, storing, and sharing still and video images. Other comments pertaining to the camera were that the users anticipate a need for autofocus and zoom capability, as well as night vision capability.

6.3 AUDIO SYSTEMS

The audio systems performed very well. In order to reduce ambient noise, the speaker was placed near or in the ear relatively easily. Some training and experience were required to properly place the noise-canceling microphone.

The independent voice control, the communications (radio) system and the speakers worked reliably. The function and utility of the speaker and microphone will need to be tested more extensively in a noisy environment. According to Mr. Sampson, "Headsets that allow hearing of the environment, as well as messages and sounds through software and radios and provide some hearing protection would be recommended."

6.4 SUMMARY OF FT. POLK USER EVALUATION

The system performed very well but there are a few design modifications essential to bring the system to an optimized level of performance for hardened military use. Final decisions about which changes will be made may require selected performance tests and experiments based on real-world scenarios. Final optimization will require that the user, design engineer and the human factors expert collectively determine the changes, based on operational test and evaluation of the system, the software and the subcomponents. Suggestions and recommendations for design changes may then be reviewed objectively for utility in the field.

7 SYSTEM REVISION AND FINAL DELIVERABLES

The preliminary user trials at Ft. Polk in October-November of 2000 identified several areas for improvement. The users were pleased with the potential capabilities of the system. However, the weight of the system on the head and awkwardness in operating the camera were mentioned several times. In particular, users found it difficult to aim the camera and manually capture an image and initiate a search. The difficulty was further exacerbated by the camera frame rate, which was limited by the available bandwidth and the ability for image compression/decompression. The system revision thus targeted these specific areas:

- Camera redesign to incorporate an Omnivision sensor and control chip set with built-in compression for higher frame rates.
- Automatic face recognition capabilities in the software.
- VGA display for reduced size, weight and power consumption.

7.1 CAMERA

A primary goal of the system revision was to improve the camera performance. The first issue with the camera was a barely adequate frame rate, which made it difficult to aim the camera and capture an appropriately framed image of the subject's face. The camera response to rapid changes in illumination conditions and backlit scenes was also targeted for improvement. At the start of this development program the selection of miniature CMOS sensors was limited, and the Hyundai chip was the most appropriate choice. At the time the system was revised, we again investigated the available chips on the market, and found that the Omnivision OV7640 sensor and 511+ USB controller would offer superior performance. This sensor and controller offer firmware compression which would significantly increase the frame rate of the system. Furthermore, readily available driver software could be used to better control the camera performance, without resorting to custom software. The use of off-the-shelf software also increases the reliability of the software and makes compatibility with future operating system and application software combinations more likely, thus enhancing the modularity of the system. Finally, we found that the auto-exposure and backlight compensation functions of this sensor was more reliable than that of the Hyundai chip. The Omnivision is available in the same package as the Hyundai chip, so the mechanical design of the camera required only minor modifications. Since the sensor is available in either full color or monochrome formats, several of the cameras were fabricated with monochrome sensors. The monochrome cameras should offer better light sensitivity and resolution, since the color cameras use a Bayer pattern pixel arrangement.

At this point, it was decided to retain the USB 1.1 format of the camera. While its bandwidth is limited to 12Mbps, it is a commonly available, mature interface which maximizes the flexibility of the system and permits us to leverage existing software and hardware. With compression, the hardware offers frame rates of up to 15 fps for full

VGA, 30 fps for QVGA and CIF format. The CMOS chip and drivers permit reduced resolution to be obtained using either windowing or decimation, depending on the needs of the application (field of view vs. resolution). In the future USB 2.0 or Firewire (IEEE 1394) will remove the bandwidth limitation and allow for higher frame rates or reduced image compression. However, neither Firewire nor USB 2.0 are available yet on a suitable wearable computer.

7.2 AUTOMATIC FACE RECOGNITION: FACEIT SURVEILLANCE™

Under a subcontract to MicroOptical, Visionics Inc., (now Identix Inc.) was tasked with improving the performance and usability of the face recognition function of the software. This effort focused on incorporating automatic face recognition mode This function relieves the user from the need to manually aim the camera, capture the image, and initiate the database search. The manual image capture and recognition function was also retained and upgraded to the latest face recognition algorithms, to allow better certainty in marginal cases and for optimal image capture for enrollment in the database.

Figure 35. Screen Shot of Face Recognition Interface for Digital MP Software.

A screen shot of the face recognition application is shown in Figure 35. Two different face recognition algorithms were implemented to improve the system performance. Using the FaceIt Surveillance™ software developers kit (SDK) from Visionics, the application automatically recognizes faces in the video stream for greater user convenience. The FaceIT Identification SDK™ utilizes manual camera pointing and image capture for higher accuracy of the face matching. In the envisioned use, the system would normally operate in automatic mode, constantly monitoring the video input stream and attempting to match faces against a database of known individuals. When a face is captured, the system automatically displays the three best matches in the windows at the bottom of the screen. The user then has the option of dealing with the individual based on the comparisons provided. The user can either share the matches with his or her supervisor over the network, or switch to manual mode for finer control of the system. In manual mode, the user can recapture the image for better image quality or enroll the subject into the surveillance database. The number of images presented to the user was intentionally limited to three, as a wearable environment is not conducive to handling complicated cognitive tasks.

7.3 VGA CLIP-ON DISPLAY

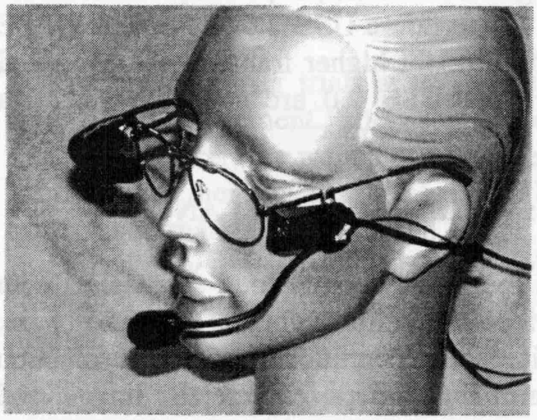


Figure 36. Headset Incorporating VGA Display with Camera and Audio.

As part of the software revision, the graphical user interface was optimized to streamline the information presented to the user. The interface was simplified so the MP can keep his attention on the subject, who, after all, may pose an immediate physical threat. This also allows us, in most situations, to replace the 20° horizontal field of view SVGA display with a 16° field of view VGA display. Proportionally, the VGA occludes even less of the field of view of the user because it utilizes a transmissive AMLCD (from Kopin Corp.) which uses a miniature backlight rather than a beamsplitter for illumination. The use of a smaller display and optimized software thus improve the user's situational awareness in two ways: first by streamlining the information for more efficient reference and second by allowing a freer view of the surrounding scene. Using the VGA display significantly lightens the load on the wearer's face, at 35g compared with 67g for the SVGA display. A photograph of the new headset is shown in figure 36.

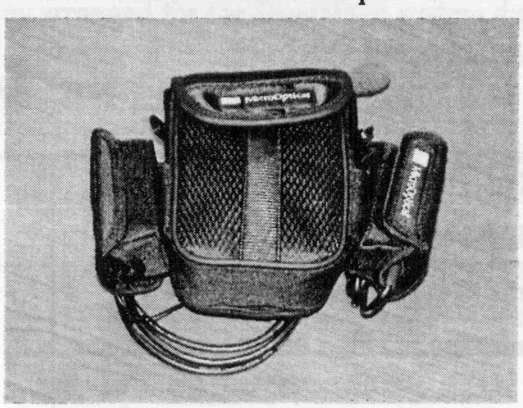
MicroOptical's first VGA display, the SV-9 (originally known as the CO-3) was conceived as an interim head-mounted display device for the MMIM program. The SV-9 was designed to accept a VGA video signal from a wearable PC and display that signal on the field sequential color LCD display used in the MicroOptical HMD. The core design was derived from a MicroOptical VGA demonstration board that was redesigned for reduced power consumption and physical size. The redesign incorporated state of the art CPLDs (Complex Programmable Logic Devices), low power memories and a video input processor. A board outline of 65 x 85 mm provided a wearable package when coupled with a standard lithium ion rechargeable battery. The complete system consisted of a three-board package to accommodate switches and connectors. The boxed unit measured 115 x 45 x 75 mm without the camcorder battery. The front panel provided a standard female 15 pin high density D connector for the VGA source, a power switch, and a switch to rotate the image for left or right eye operation. The back panel consisted of a machined battery holder, a power jack for an AC adapter and a switch to enable a high brightness monochrome mode. The circuit provided a 24-bit data path (8 bits per color or 16,777,216 colors) and consumed 4 W in normal brightness mode and 4.5 W in high brightness mode.

The SV-6 was conceived as a replacement for the SV-9 that would incorporate more features in a smaller, lower power package. The size reduction was primarily made possible by advances in circuit integration and packaging. New low power, high-density memories and high efficiency power supplies were employed to reduce overall power consumption. A board outline of 70 x 38 mm was chosen to match the footprint of the lithium ion rechargeable battery used to power the system. Switches, battery terminals, LED indicators and the head unit connector were all positioned on this single board. A cable with a 15-pin high density D connector on one end terminated to wirelaps on the system board. The complete package excluding cables, battery and strain reliefs measured 78 x 42 x 17 mm. The SV-6 incorporated a 3-button, 6 LED user interface to provide control of horizontal size, brightness, horizontal position, vertical position and left or right eye flip. The circuit provided an 18-bit data path (6 bits per color or 262,144 colors) and consumed only 1.8 W in normal brightness mode and 2.7 W in high brightness mode.

The SV-6 added features while reducing size and power consumption. The only compromise in performance in relation to the SV-9 is in bit depth. Most computer applications do not require 24-bit color. Power was reduced by 40% to 55% depending on operating mode. Physical size was reduced by 86%. Usability and interoperability were dramatically improved by the SV-6.

7.4 SYSTEM INTEGRATION AND FINAL DELIVERABLES

The complete MMIM system consists of VGA display, USB camera, speaker, boom microphone, and mouse. A photograph of an MMIM unit is shown in Figure 37. Most of the systems are configured with a USB audio adapter for maximum reliability; one system is configured with analog audio for computers without an available USB port, and one system is configured with an off-the-shelf Bluetooth wireless audio interface to demonstrate wireless connectivity. Similarly, the mouse may utilize either a USB or a PS/2 port depending on the computer (adapters are commercially available). Three of the MMIM headsets were configured for ruggedized Exponent wearable computers supplied by the Natick Soldier Center, by replacing the standard connectors with sturdier Lemo connectors and configuring the VGA display to receive power from the wearable computer battery. These systems were incorporated into a military vest compatible with the body armor typically worn by MP's. The result is a wearable system prototype suitable for demonstration and pilot trials in military settings. A photograph of the system



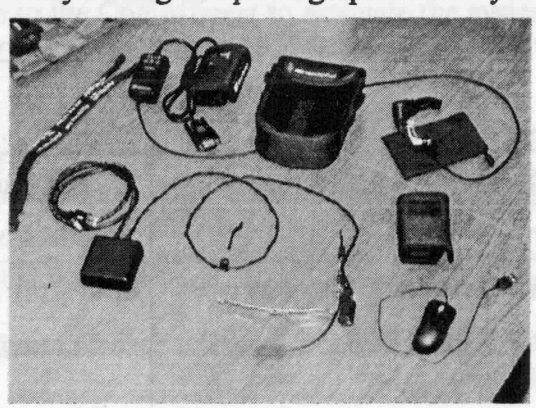


Figure 37. MMIM Headunit

is shown in Figure 38. The rest of the systems are configured for use with standard laptop computers or commercially available wearable computers such as the Via II™ or Xybernaut™ computers.

Figure 38. DMP Vest with Wearable Computer and MMIM Headset.

7.5 DEMONSTRATION TO THE U.S. NAVY 6TH FLEET

Navy 6th Fleet, Gaeta, IT
July 14-18, 2003

7.5.1 Attendees:

Table 5: Navy Demonstration Meeting Attendees

Office Of Naval Research: http://www.onr.navy.mil

Role	Name	
NR ONR S&T 201 **Project Lead**	**LCDR Hoa Ho, USNR** **hoa.thi.ho@intel.com**	
NR ONR S&T HQ 106 **C6F NRSA Liaison Naval Officer**	**CAPT(s) Todd Morgan, USNR** **todd.morgan@wpc.af.mil**	
C6F Naval Research Science Advisor (NRSA)	**Mike Halloran** **c6f020b@c6f.navy.mil**	

Role	Name	
Naval Fleet/Force Technology Innovation Office	**Dr. John Mittleman**	
Naval Fleet/Force Technology Innovation Office, Assistant	**Eric Evans** **Eric_Evans@onr.navy.mil**	

U.S. Army Soldier System Command: http://www.natick.army.mil

Role	Name	
Facial Recognition Program Manager, Army Technical Lead	**Mark Chandler** **Mark.Chandler1@us.army.mil**	

MicroOptical Engineering Corporation: http://www.microoptical.net

Role	Name	
Hardware OEM Contractor **HMD Manufacturer** **Electrical Engineer**	**Evan Weststrate** **eweststrate@microoptical.net**	

7.5.2 Purpose:

The Navy's 6th fleet is interested in fulfilling a need to supplement their security force with a facial recognition system. Mike Holloran, technology officer with the 6th Fleet, directed LCDR Hoa Ho and CAPT(s) Todd Morgan to investigate the hardware and software technologies currently available for possible use on a 6th Fleet security team. They arranged for the DigitalMP system demo to the C6F officers to evaluate the system.

7.5.3 Activities:

1. Initial meetings and general discussion
2. Demonstration and detail evaluation of the DigitalMP system to ONR personnel in an informal, hands-on setting
3. Demonstration to two visiting US Marine personnel
4. Preparation of the C6F staff briefing
5. Active capture and build of attendee face database with the DigitalMP system in and around the base offices
6. Database management and copy to all wearable machines
7. Staff briefing, live demo, and Q&A
8. C6F Science Advisor receives and evaluates feedback
9. Preparation of the C6F Admiral's briefing

10. Briefing and request for support – Vice Admiral Scott Fry
11. Closing meetings and feedback discussion

7.5.4 Meeting Notes:

The technical demos to the C6F staff included a live face capture/enroll of certain officers and staff members and a mock interrogation and recognition. Also, a face capture and recognition with a known terrorist database was demonstrated. Many officers, including the admiral, were able to don the vest and try out the system themselves.

Several of the ONR staffers remained skeptical of the Identix software's robustness with various quality and size databases. Most of the Q&A from the C6F staff and the ONR staff focused on the Identix software.. Mark Chandler would arrange a conference call with Identix and the ONR to hopefully address some of the unanswered issues.

The primary goal of the meeting with the USN 6th Fleet was accomplished with the admiral expressing his support for continuing the evaluation of the a facial recognition system. This went along with the general support of the staff officers, although the Navy's requirements do not necessarily include a wearable system. There is a need for the facial recognition piece, but the final form is TBD.

8 Conclusions

The MMIM/DMP project resulted in the development of a complete wearable computer interface, complete with display, camera and audio. Two different displays were demonstrated: a high resolution, 20° horizontal field of view SVGA display and a more compact 16° VGA display. The headset also incorporated a VGA camera based on a CMOS chip and utilizing a standard USB interface, as well as high quality audio components.

This headset was incorporated into a complete wearable system, including wearable computer, mouse, and wireless communications capability and demonstrated with software designed to aid the MP in his or her duties. Specifically, this project demonstrated that in order to optimize the user experience, both the hardware and the software must be designed with the end-user and environment in mind. Situational awareness is achieved both by minimizing the weight and size of the equipment and by automating tasks to reduce the cognitive load on the user. These principles were showcased in a wearable system providing mobile face recognition capability (Fig. 39).

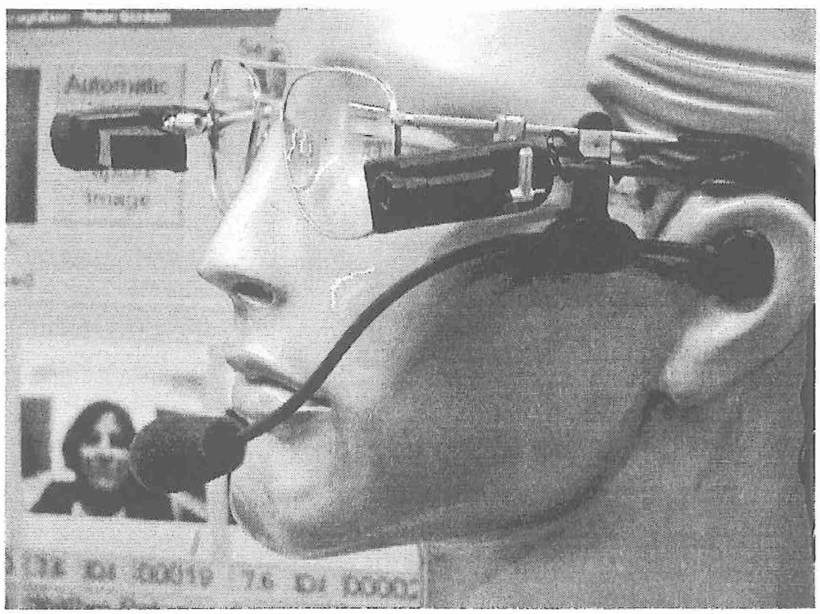


Figure 39. MMIM Headset and DMP Software.

This document reports research undertaken at the U.S. Army Research, Development and Engineering Command, Natick Soldier Center, Natick, MA, and has been assigned No. NATICK/TR- 04/014 in a series of reports approved for publication.

References

[1] M. B. Spitzer, N. M. Rensing, R. McClelland, and P. Aquilino, "Eyeglass-Mounted Displays For Wearable Computing," *Record of the First International Symposium on Wearable Computing,* Cambridge, MA 1997. M. B. Spitzer, P. D. Aquilino, M. H. Olson, R. W. McClelland, N. M. Rensing and P. M. Zavracky, "Video I/O interface for wearable computers," *Proceedings of SPIE Conference 3689, Helmet and Head-Mounted Displays IV,* Orlando, Florida, April 5 and 6, 1999.

[2] OSHA Standard 1910.95c1.

[3] J. B. Sampson, "Digital-MP Evaluation Trials: Observations and Comments, 30 October to 3 November 2000, Fort Polk, LA" (unpublished).

[4] M.B. Spitzer, P. M. Zavracky, N.M. Rensing, J. Crawford, A. H. Hockman P. D. Aquilino and H. Girolamo, "Multi-functional Micro-controllable Interface Module", to be published in SPIE Proceedings #4361, Helmet and Head-Mounted Displays VI.

Appendix: System Specification as of May 28, 2003

Table A1. MicroOptical SV-6™ Display Specifications

Resolution	640x480 pixels, 60 Hz refresh
Color depth	18 bit color
Cable length	4 ft from viewer to belt worn controls
Field of view	Approximately 16° Horizontal, 19° Diagonal
Focus range	Adjustable, 2 to 15 ft
Video input	Standard VGA, male DB-15 connector
Power requirement	1.6 W
Battery	7.2 V LiIon rechargeable, 4 hours battery life/2cell battery
Viewer weight	1.25 Oz

Table A2. Camera Specifications

Sensor	640x480 pixels, 1/3" active area color CMOS sensor
Frame rate	15 fps @ 640x480, 30 fps @ 320x240
Cable length	4 ft from eyeglasses to control box
Field of view	Approximately 19° Horizontal
Optics	19 mm f/# 7 lens
Focus	Adjustable, 2ft to infinity
Computer interface	USB 1.1
Weight on head	1.25 Oz

Table A3. Wearable computer system specifications

Total system weight including vest, computer, and batteries	7 lbs
Weight of head mounted components	4 Oz
Processor	500 MHz Pentium III™ or Crusoe™ (min)
Memory	256 MB (min)
Operating system	Microsoft Windows 2000™
Runtime	Approximately 4-6 hours battery life, hot swappable
Networking	802.11b wireless LAN
Standard interfaces	VGA out, 2 USB 1.1 ports (min), Keyboard, Mouse, analog audio in/out

Table A4. DMP Software Specifications

Face recognition software	FaceIt Identification™ and FaceIt MultiFace™ SDK's by Identix, Inc. SDKs available for Windows and Unix. Custom solutions also available.
Images in database	Unlimited (depending on available computer resources)
Search time to find face	50-300 mS
Data base search/match	Up to 60 million/minute from memory
Data base source images	Any digitized image including photographs, video, and artist renderings
Pose	Optimal performance with frontal images, accurate up to 35° off-axis. Less accurate with images between 35 and 90° off-axis.
Accuracy	Depends on user settings, database size and image quality. Always displays top 3 matches for final user verification. See FRVT2002 for independent government study of accuracy for watch list, one-to-many and one-to-one matching.
Speech recognition	Via Voice™ SDK by IBM
User interface	Proprietary GUI developed for DARPA and US Army SSCOM

Table A5. Contacts

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